PAPER NO. 81-1077

SOME ENGINEERING ASPECTS OF THE NICHOLSON-KOCH MOBILE CHIPPER

BY

Donald L. Sirois
Project Leader
Engineering Research
Southern Forest Experiment Station
U.S. Forest Service
Auburn University, AL 36849

For presentation at the 1981 Summer Meeting
AMERICAN SOCIETY OF AGRICULTURAL ENGINEERS

Sheraton-Twin Towers
Orlando, FL
June 21-24, 1981

SUMMARY:

A proto-type mobile chip harvester has been designed to harvest forest biomass in the form of logging residuals for use as energy wood. The proto-type is presently undergoing developmental tests. Results are encouraging, indicating mechanical feasibility with prospects of working systems within the next several years.

ASAE

American Society of Agricultural Engineers

St. Joseph, Michigan 49085

SOME ENGINEERING ASPECTS
OF THE NICHOLSON-KOCH MOBILE CHIPPER

INTRODUCTION

The United States is running out of oil and natural gas. Production limitations by oil producing countries are causing energy shortages and rapidly increasing prices. Air pollution regulations and high costs are holding back the use of coal as an alternative fuel. These facts have led to increasing interest in biomass as a clean renewable energy source. Forest biomass and residues could be a major source of renewable energy. Jamisons (1979) tells us that the question is not so much will we use biomass as an alternative energy source, but more a question of when should we make the switch. The switch has been made by a number of companies in the forest products industry that have local supplies of mill residues available to them at low cost. On a a national average, the industry is now 40 percent energy self-sufficient (Arola 1976).

Of our Nation's total energy needs it is estimated that forest products are now contributing about 1 1/2 percent, or 1.16 x 10^{16}kJ (1.1 x 10^{16}BTU's), to an estimated 79.1 x 10^{16}kJ (75 x 10^{16}BTU's) annual national energy consumption. This input includes energy from all forms of wood products and residues, including such products as black liquor from the kraft pulping process. It is projected that the wood energy could provide up to 5.5 x 10^{16}kJ (5.2 x 10^{16}BTU's) annually in the relatively near future. But this would depend on better utilization and more complete harvesting of portions of the forest resource such as weed trees and residues, which are now a disposal problem for landowners and forest managers.

Companies such as Boise Southern and Isenhour Brick and Tile Company have implemented harvesting of growing biomass to supplement their energy needs. The Isenhour Company, a non-forest industry, established a forest products subsidiary to purchase mill residues and begin a fuel wood harvesting operation. Using conventional logging equipment at an investment of about $500,000 it has been reported that they can produce up to 227 tons (250 short tons) of fuel chips a day at two-thirds the cost of No. 2 fuel oil (Bryan 1978). Unfortunately, conventional logging equipment is not capable of economically harvesting brush, small wood (trees under 12.7 cm (5 in) DBH), and logging residues in the form of tops, limbs, and downed materials. These materials are usually left in the woods because harvesting costs exceed their energy value when using conventional harvest equipment and systems. If the harvesting operation is unable to cover its cost from the value of usable products, then other credits such as site preparation and stand improvement must be found. To be economical with present conventional systems, an energy wood harvesting operation must be in stands that include large trees (Klunder 1979). Because of these considerations, at least two machines are under development in the United States to harvest forest biomass in the form of smallwood and logging residuals (Smith 1978, Koch 1978). In an attempt to improve the economics of harvesting these materials, the machines--

the Georgia-Pacific Fuel Wood Harvester and the Nicholson-Koch Mobile Chipper--both rely on the swath felling and processing of multiple stems into chips as the machine travels through the forest. This paper deals only with the Nicholson-Koch Mobile Chipper.

DEVELOPMENT OF PERFORMANCE CRITERIA

During late 1976 and early 1977, several meetings were held between five forest products companies with Southern operations, the Department of Energy, and the Forest Service to discuss the possibility of a cooperative effort for the development of a mobile fuel wood harvesting system. The basis of the system was a general concept presented by Dr. Peter Koch of the Forest Service. The outcome of these meetings, which included presentations by equipment manufacturers of possible hardware, resulted in the development of the following performance goals:

While traveling at a rate of 1.6 km/h (1 mph), be able to fell and chip trees of the major southern hardwood and softwood species measuring up to 30.5 cm (12 in) in diameter at a 15.2 cm (6 in) stump height.

Clear fell all trees under 30.5 cm (12 in) diameter at stump height, and cut high stumps within a complete swath 280 cm (110 in) wide.

Be capable of picking up, feeding, and chipping previously felled trees up to 48 cm (19 in) in diameter.

Pickup, feed and chip logging slash and other downed material while traveling at a rate of 1.6 km/h (1 mph).

The design of the machine is to be such that an average travel/work speed of 1.6 km/h (1 mph) is possible over sites containing 56.5 tons (62.5 short tons) of green above-ground forest biomass per hectare (2.5 acres) while felling, feeding, and chipping this material.

The average production rate is to be 0.4 ha (1 acre) per hour on sites containing 22.6 tons (25 short tons) of forest biomass. The harvesting efficiency, measured as percent of biomass on the land that is chipped and transported from the site, is to be 85 percent or more.

The ground pressure of the machine is to be less than 83 kPa (12 psi).

Based on the above criteria and information presented by six equipment manufacturers on possible concepts, an agreement was entered into with Nicholson Manufacturing Company of Seattle, Washington for the design and development of the present machine known as the Nicholson-Koch Mobile Chip Harvester. Several of the performance criteria related to percent of biomass harvested and tons of chips produced per hour are based on an economic analysis by Koch and Nicholson (1978). Their analysis indicated that for the proposed chip harvesting system (one mobile chipper and two chip forwarders), at least 19 tons (21 short tons) of chipped biomass would have to be delivered to road side for each machine operating hour. Based on assumed cost in the analysis, it was projected that green chips could be delivered to a mill for $12.31 per ton ($13.57 per short ton). Because of inflation, Koch (1980) revised this figure to $16.32 per ton ($18.00 per short ton). Figure 1 is the prototype machine designed and built by Nicholson Manufacturing Company to meet the criteria.

Table 1. General specifications of the Nicholson-Koch Mobile Chipper

	SI Units	English Units
Gross vehicle weight (including all fluids)	33,106 kg	73,000 lbs
Approximate ground contact area with 51 mm (2 in) penetration of tracks	43,473 cm^2	6,740 in^2
Approximate ground pressure	0.74 kPa	10.8 psi
Engine power	428 kW	575 HP
Drum chipper characteristics		
cutting-circle diameter	1219 mm	48.0 in
Sprout width	1206 mm	47.5 in
Number of knives	3	3
Drum speed	544 r/min	544 rpm
Nominal feed speed	41.4 m/min	136 ft/min
Felling bar characteristics		
Cutting circle diameter	419 mm	16.5 in
Length	2375 mm	93.5 in
Number of knives	4	4
Rotational speed	0-800 r/min	0-800 rpm
Clearance above ground	51-178 mm	2 to 7 in
Diameter of side feed rolls	610 mm	24 in
Machine ground speed	creeping to 4.8 km/h	creeping to 3 mi/h

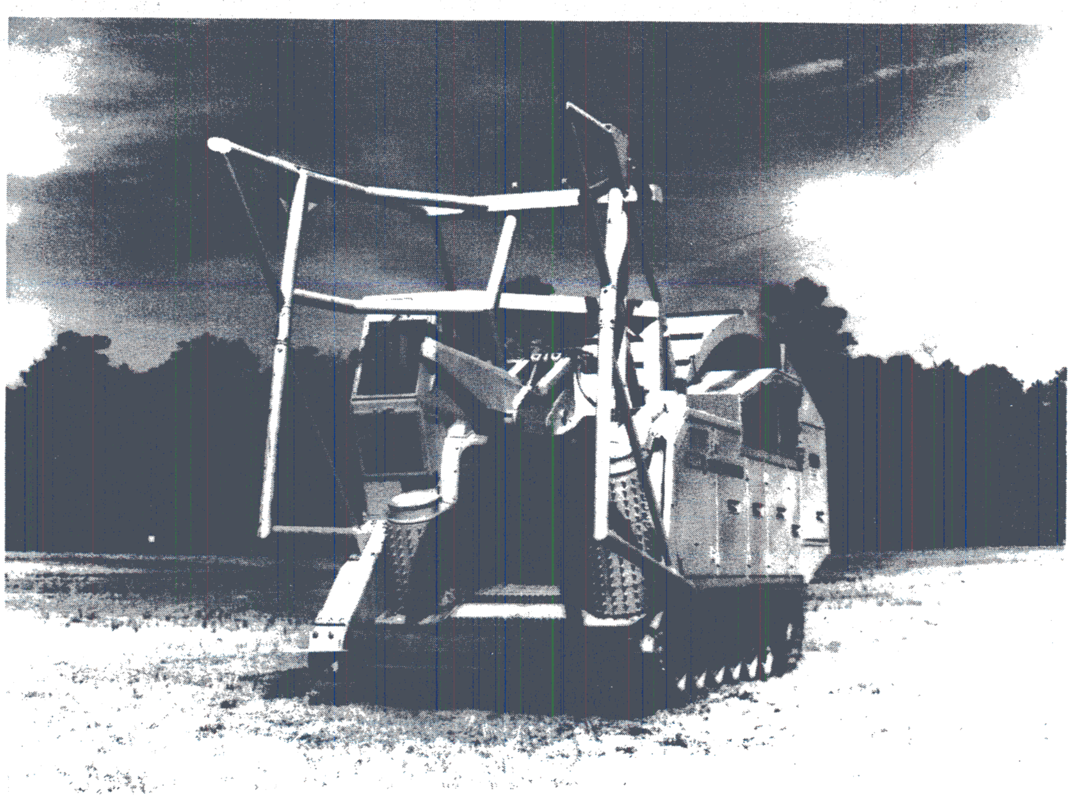

Figure 1. The Nicholson-Koch mobile chip harvester.

MOBILE CHIPPER DESIGN FEATURES

The mobile chipper (as seen in Figure 1) is a large machine with overall dimensions of 2,870 mm (113 in) in width and 10,010 mm (394 in) in overall length. In the working configuration the overall height is 4,570 mm (180 in). With the chip discharge chute and front tree collector frame folded down for truck transport the overall height is reduced to 3,510 mm (138 in). Some of the other specifications are shown in Table 1.

The most unique feature of the Nicholson-Koch Mobile Chip Harvester is the "felling bar" and its related drive system. In addition to severing standing trees and brush over a 2,335 mm (93.5 in) wide swath, the felling-bar also has the ability to pick up large, previously felled trees and other downed materials and to assist infeed into the drum chipper. Figure 2 shows some of the design features of the felling bar.

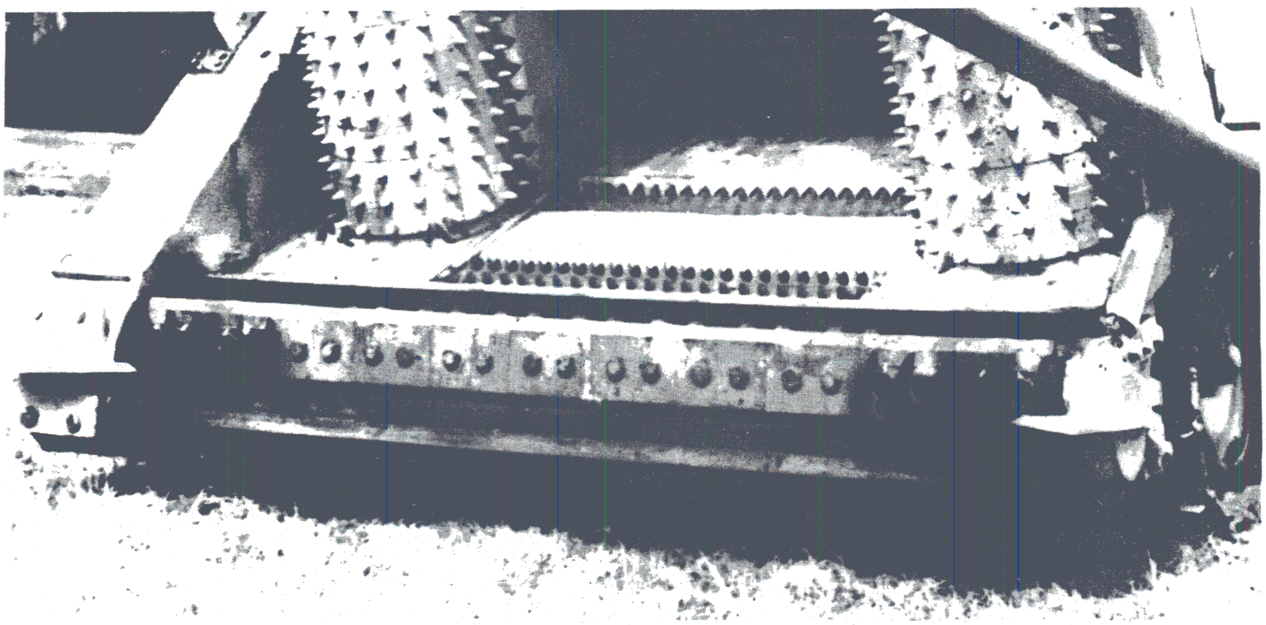

Figure 2. Nicholson-Koch felling bar.

Since the Nicholson-Koch feller bar is a new concept for felling trees there was a need to conduct laboratory type tests on a model to determine cutting characteristics, power requirements and forces that would be experienced by the feller bar support bearings and machine chassis. The first tests were conducted on a 1,220 mm (48 in) long, 406 mm (16 in) diameter, 4 knife model. The model was instrumentated to measure power input and the vertical and horizontal thrust. Controls were such that forward speed of the feller bar, or the rate of travel through a tree, could be controlled from creeping to 3.2 km/h (2 mile/h) and rotational speed was variable up to 1,000 r/min (1,000 rpm). These tests, conducted in 1978, using the sections of a western hardwood species with a specific gravity of 0.55 (oven-dry volume and weight basis), indicated that peak power requirements while simulating the felling of 18.8 cm (7.4 in) diameter trees were generally under 298 kW (400 hp) and varied with rotational speed (Koch and Nicholson 1978). The test also indicated that during felling, the downward, vertical thrust of the feller bar varied with tree diameter and species, with forces of up to 71.2 kN (16,000 lbf) being observed. The horizontal force was generally low and if stalling of the feller bar rotation was avoided, did not exceed 13.3 kN (3,000 lbf). Based on this information, the Nicholson Manufacturing Company built a 2,440 mm (96 in) long feller bar and mounted it on a rail wheeled test car along with a prototype two knife drum chipper. The feller bar was set up to be driven by a 321 kW (430 hp) diesel engine using belts. The chipper was also belt driven using a 224 kW (300 hp) electric motor. As reported by Koch and Nicholson (1978) test runs using this prototype mock-up indicated that the power to the feller bar appeared adequate for simulated felling of hickory (Carya spp.) trees up to 30.5 cm (12 in) in diameter with forward test car speeds between 0.8 and 1.2 km/h (0.5 and 0.75 mph). Chipper power requirements were found to be a function of the tree diameter and dependent on species. Figure 3 shows the results of the Nicholson chipper tests.

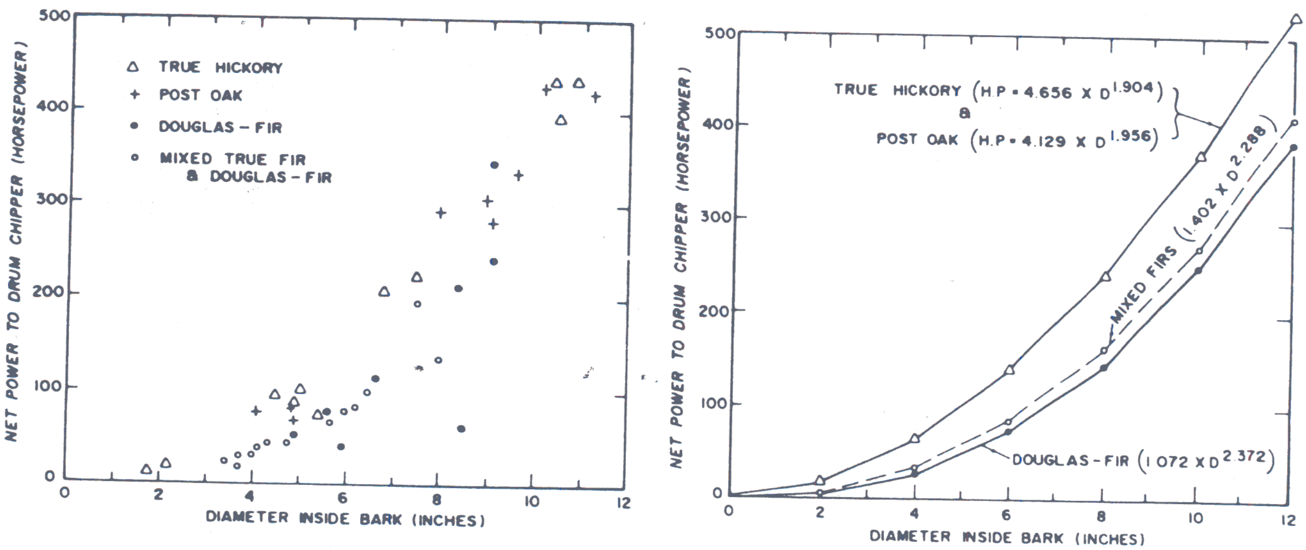

Figure 3. Net power requirements of the prototype 1,220 mm (48 in) two knife drum chipper turning at 550 r/min. (550 rpm). Average feed rate was 29 m/min (95 ft/min) with green logs. Left graph pooled data and curves fitted to data by species on right graph. (Graphs taken from Koch and Nicholson (1978)).

Based on the test results using the prototype mock-up, Nicholson's engineers incorporated the feller bar design into the field test prototype with only minor changes. However, to improve the self-feeding of the drum chipper they increased the number of knives from two to three. It was estimated that the addition of the third knife would increase the input power requirements by 50 percent without changing the specific energy requirements.

The results of the model testing showed that although the feller bar has high input power demands, these are short in duration, lasting only a few seconds. Based on this information, it was decided not to increase engine power to handle these brief peak loads, but to design the power train so that the stored rotational energy of the drum chipper could assist in meeting the peak power requirements of the feller bar. The combination of mechanical and hydraulic drives shown in Figure 4 accomplishes this.

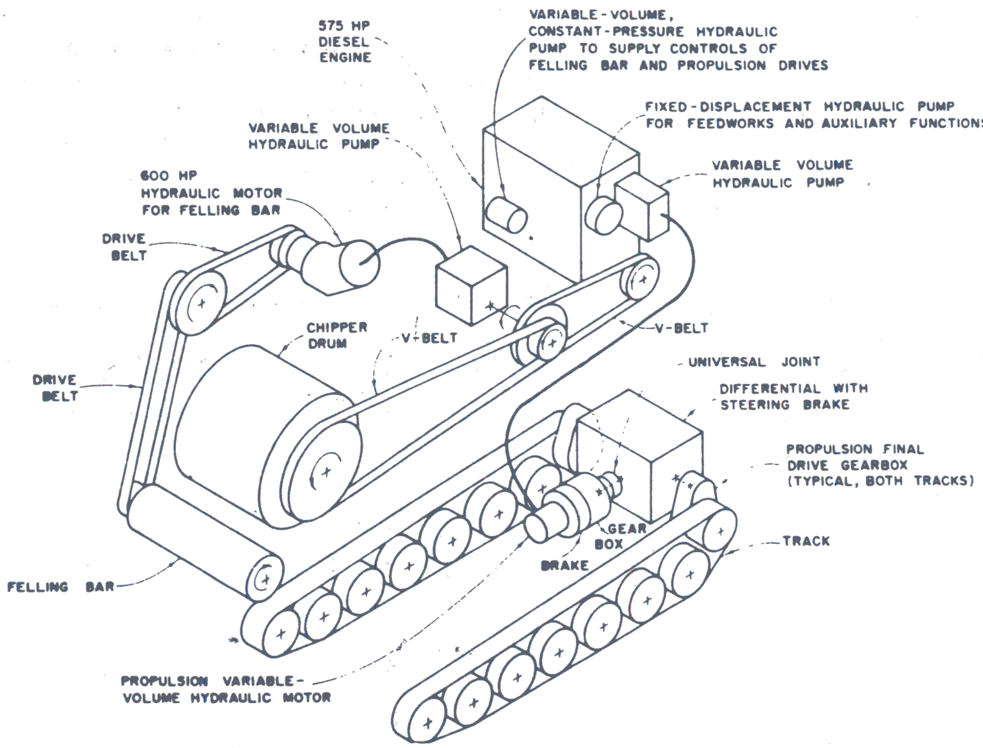

Figure 4. Schematic diagram of the Mobile Chip Harvesters' major components and power trains.

POWER TRANSMISSION SYSTEMS

Because of the wide range of terrain and forest biomass operating conditions as well as lack of previous engineering field experience with a machine similar to the Mobile Harvester, it was necessary to build in as much flexibility as possible for power flow while maintaining a high power transmission efficiency to keep engine power within a tolerable limit. The systems shown by the schematic diagram of Figure 4 accomplishes this to a high degree.

All power is supplied by a single Cummins KTA-1150-C600[1/] diesel engine rated at 429 kW (575 hp) at 1,900 r/min (1,900 rpm). Our field

[1/] Use of trade names is for the information of the reader and does not constitute endorsement by the U.S. Department of Agriculture.

tests during 1980 and 1981 in Alabama have indicated that the present power plant has been adequate for all operating conditions encountered so far. This includes felling trees up to 41 cm (16 in) DBH at a slow forward speed under 1.6 km/h (1 mph), cutting of high stumps up to 76 cm (30 in) in diameter, and chipping trees up to 48 cm (19 in) in diameter.

Figure 4 shows that the power from the engine flows through two main transmission paths--the propulsion drive and the chipper/feller bar drive. The propulsion power is transmitted by a hydrostatic transmission system using a Rexroth variable displacement axial piston pump and motor. A two speed gear box provides a low and a high speed range going into the differential. The differential, final drive, tracks, and chassis are all adapted from an FMC series 200 logging skidder. The FMC Series 200 is normally powered by a 146 kW (197 hp) diesel engine, therefore it was felt that the propulsion power should be limited to 112 kW (150 hp) to prevent components from being subjected to higher loads than they were originally designed for, which cause reduced life. Because of the heavy weight of the prototype machine, 33,113 kg (73,000 lbs), the power limitation has caused some minor operational problems. One of these has shown up as transmission stall (pressure by-pass) during wet boggy conditions and when climbing up short steep, pitch slopes. Generally, these conditions can and should be avoided. A reduction in weight for future machines would improve performance under poor terrain conditions.

Power for the chipper and feller bar is taken from the main output shaft of the engine. Chipper power is transmitted through a mechanical Twin Disc clutch and two Kevlar reinforced Goodyear "Torque-Team-Plus" banded V-belts with an intermediate shaft. The belts are 5V section with 12 ribs on the primary belt and 13 ribs on the final drive. The belts are capable of transmitting full engine shaft power when needed. This drive system has proven trouble free during the past field tests.

When the feller bar is operated, the engine shaft power is divided between the chipper and feller bar drive at the intermediate shaft. The feller bar power is controlled and transmitted through a hydrostatic transmission and belt system. Based on the peak power requirements observed during the pre-prototype model tests, Nicholson's engineers designed the feller bar system for loads up to 448 kW (600 hp). Even though the engine is rated for only 429 kW (575 hp) and there are parasitic loses, it is possible to obtain higher power input for short periods because of the mechanical drive arrangement of the chipper. This is essentially a two-way drive that permits stored, fly wheel energy of the rotating drum chipper to be directed back to the intermediate shaft and into the feller bar drive pump. The pump for the feller bar drive is a Rexroth axial piston variable displacement pump. The motor is a Rexroth fixed displacement axial piston motor. In order to keep the size and weight of this system at a reasonable level, considering the power involved, the system is designed to operate at working pressures of 31,030 kPa (4,500 psi). Initially the high system pressures resulted in a number of hydraulic system leaks. Most of these were the result of defective materials and installation problems. Since the initial startup problems were corrected there has been no recurrence of the problems.

The original design of the belt drive between the feller bar motor and feller bar was based on the use of positive synchronous cog belts.

Two belts were used with intermediate idler sheaves as shown in Figure 4. This design did not prove to be adequate for the field test conditions encountered and resulted in a high failure rate. In the criteria, it was specified that the feller bar be capable of felling standing trees and cutting off high stumps that are up to 30.5 cm (12 in) in diameter at 15.2 cm (6 in) above ground level. During field test operations it was not possible to stay within the diameter limit and still simulate a production operation. Occasionally, larger trees were encountered as well as a number of large stumps, up to 76.2 cm (30 in) in diameter, that were hidden from view of the operator and ground spotter. Examination of the failed belts by the manufacturer resulted in the conclusion that the belts had experienced severe shock loads causing the belts to rachet. This racheting sheared off one or more drive lugs allowing the belt cord line to run on the pulley, causing belt failure. Some belts did not show evidence of racheting and subsequent wear, but appeared to have failed under high tensile load. Based on later tree felling test results, it is very probable that the belts were subjected to very short power peaks in excess of 408 kW (547 hp).

Because of the high failure rate, it was decided to redesign the belt drive using banded, joined, Kevlar reinforced V-belts. The banded V-belt used for the primary drive from the motor is a 5V section 8 rib belt, and the final drive is a 5V section 12 rib belt. During the first few hours of the January 1981 field test, the new drive system was subjected to high peak power requirements caused by chance encounters of the feller bar with large diameter stumps. These encounters caused some slippages of the V-belts, however no failures occurred. After about ten hours of operation,the belts were re-tensioned. No perceptible slippage has been noted since re-tensioning of the belts.

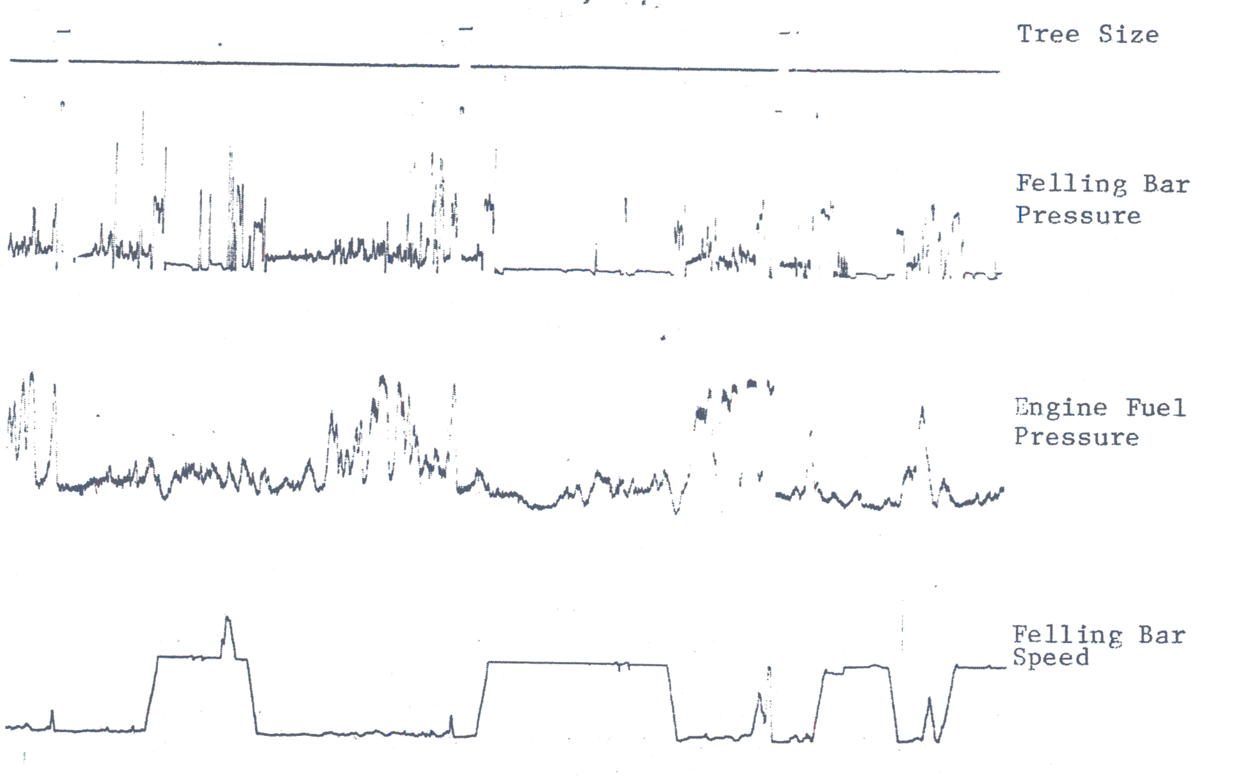

Figure 5. Sample chart showing engine fuel pressure,felling bar hydraulic pressure, felling bar speed, and tree size.

During several periods of field testing it was possible to instrument the feller bar drive so that the required parameters needed to calculate power could be recorded on a strip chart (Figure 5).

From strip charts similar to the sample, Figure 5, peak and average feller bar input powers were calculated. This was done by determining the peak and average hydraulic pressure to the feller bar motor and the motor speeds. Motor efficiencies were obtained from a graph provided by the motor manufacturer. Power was calculated using the following equations:

$$T = \frac{Vg \times P \times E}{24\ \pi}$$

and

$$FP = \frac{T \times m}{c}$$

where: FP = Feller bar power (at motor shaft)
T = Torque
P = Pressure acting on pump (net)
Vg = Maximum geometric displacement of motor
E = Motor efficiency (mechanical and volumetric)
m = Motor speed
c = Constant dependent on desired power units (kW or HP)

The upper limit of the measured power to the feller bar is established by relief valves and the maximum flow rates of the feller bar hydraulic system. If the power demand exceeds the upper limit of the system, the feller bar will simply stall out and automatically destroke to zero flow. The system is reset manually.

An attempt was made to correlate sharp and dull knife powers required to fell trees by tree diameter and species. No strong correlation could be found similar to the lab tests run by Nicholson (Koch and Nicholson 1978). The possible reasons were lack of good control of forward speed for the machine and feller bar speed. Also, the uneven ground conditions in the vicinity of the tree being felled could cause vertical movement of the feller bar affecting the cutting action and power requirements. For all tree species; pine, soft hardwoods, and hard hardwoods; within the size range of 12.7 to 25.4 cm (5 to 10 in) DBH, the mean average power required to fell a tree was 110 kW (147 HP) with a standard deviation of 42.8 kW (57.4 HP) for 35 sample trees. The mean felling time was 5.6 seconds with a maximum of 8 seconds. The peak power recorded was 408 kW (547 HP). The mean peak power of all trees was 316 kW (424 HP) with a standard deviation of 42.8 (57.4). Based on the available data the only conclusion that can be drawn is that the available power to the feller bar is sufficient to meet the performance criteria. However, actual field operating conditions and operator technique may not permit full utilization of the felling capability of the machine. It was not possible to measure power input to the three knife drum chipper during the field tests. Direct observations of the chipper during production studies indicate that the chipper is well matched to the rest of the machine. Chipper feed rates for delimbed hardwood logs 20.3 to 25.4 cm (8 to 10 in) DBH averaged 47 m/min (154 ft/min) and 50 m/min (163 ft/min) for pine. These feed rates are an improvement over the rate of 27 m/min (90 ft/min) reported by Koch and Nicholson (1978) for the early two knife chipper during the lab model tests. Several hardwoods up to 48.3 cm (19 in) butt diameter that had been felled using a chain saw were completely chipped by the machine. These trees fed at a rate of less than 27 m/min (88 ft/min) requiring the machine to move forward to force feeding of the chipper. After approximately one half of the trees (two butt logs) were chipped, the chipper began to self feed. In addition to prefelling these larger trees, the main large diameter lateral branches were notched with the chain saw permitting them to fold back for improved infeed into the chipper.

The quality of chips produced by the chipper are generally good, being in the 1.9 to 3.2 cm (3/4 to 1-1/4 in) size range. The quality may be acceptable for fiber, in addition to use as energy wood, with some beneficiation treatment. Generally the pine chips were more uniform in shape than the hardwood chips. Screen analysis of chip samples of mixed pine and hardwood chips collected during normal harvesting tests are shown in table 2.

Table 2. Average size of chips produced by the Nicholson-Koch mobile chipper.

Screen Size		Percent by weight retained on screen	
mm	(inches)	Average1/	Range
<13	(1/2)	26	8-50
13	(1/2)	22.5	13-29
19	(3/4)	14.4	6-20
25	(1)	14.4	5-21
32	(1-1/4)	6.6	3-14
38	(1-1/2)	8.4	3-14
>51	(2)	7.7	4-24

1/ Average of 23 samples

CONCLUSIONS

Presently the Nicholson-Koch Mobile Chip Harvester prototype appears to be of good mechanical design. Other than the failures associated with the feller bar belt drive system when using the synchronous cog belts, no other mechanical failures have occurred that would indicate structural or other mechanical design problems. The newly designed V-belt for the feller bar is performing satisfactorily after about 50 hours of operation. A number of failures have occurred in the rather complex hydraulic systems. These have generally been related to defective materials or improper installation. With the correction of these problems, overall mechanical availability of the machine should increase.

Although additional field tests are needed to establish design changes for improving machine production, past tests indicate that mechanical performance for harvesting, felling, and chipping of forest biomass are within the original design goals established for the machine.

REFERENCES CITED

Arola, R.A.
1976. Wood fuels--how do they stack up? In Proc. energy and the wood products industry. For. Prod. Res. Soc. No. P-76-14. p. 34-45.

Bryan, R.W.
1978. Fuelwood harvesting, chipping operation encourages forestry. For. Ind. 105(9) :42-43.

Jamison, R.L.
1979. When should a company switch fuels? National Hardwood Mag. 53(1) :24-25, 36, 44.

Klunder, Richard A.
1979. The forest: a source of fuel in the paper industry. Presented paper at the Paper Industry Management Assoc. Meeting. June 15, 1979, San Francisco, CA (APA paper 79-P-15) 6 p.

Koch, Peter.
1978. Five new machines and six products can triple commodity recovery from southern forests. J. For. 76(12):767-772.

Koch, Peter and T.W. Nicholson.
1978. Harvesting residual biomass and swathe-felling with a mobile chipper. P. 146-154 In Complete-Tree Utilization of Southern Pine, Proc. Symp., New Orleans, LA. April 1978 ed. C.W. McMillin. For. Prod. Res. Soc. Madison, Wis.

Koch, Peter and Thomas E. Savage.
1980. Development of the swathe-felling mobile chipper. J. For. 78(1):17-21

Smith, F.M.
1978. Fiber for fuel. Presented at APA Meeting, Pine Bluff, AR. Paper No. 78-P-17. 4p.